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SILICEOUS OÖLITES AND OTHER CONCRETIONARY STRUCTURES IN THE VICINITY OF STATE COLLEGE, PENNSYLVANIA[1]

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The town of State College is situated near the geographical center of Pennsylvania. It lies among the erosion remnants of the Appalachian Mountain system and near the western border, where the highly folded strata of the Tussey and Bald Eagle ranges begin to flatten out into the gently dipping beds of the Allegheny Mountains. These mountains occupy the synclines of the original folds while the present valleys always lie along the original anticlines, which have suffered more rapid erosion than the synclines, permitting the streams to cut down to the base of the Ordovician system.

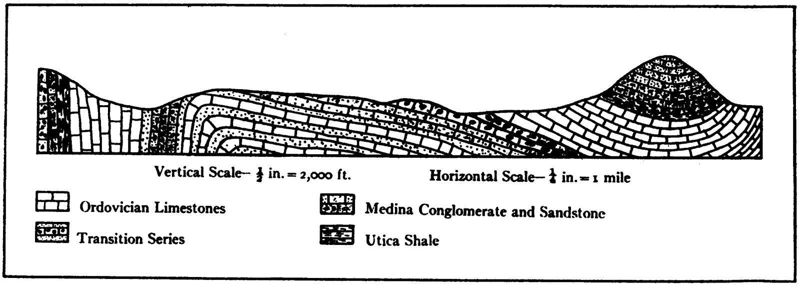
Vertical Scale— ¼ in. = 2,000 ft.
Horizontal Scale— ¼ in. = 1 mile
Ordovician Limestones
Transition Series
Medina Conglomerate and Sandstone
Utica Shale

FIG. 1.—Representative geological section through the oölitic area

A geological section through the area would show, from the oldest exposed strata upward, several hundred feet of interbedded sandstone, limestone, and calcareous sandstone, grading over in the upper layers into limestone-conglomerate in which the pebbles have not as a rule suffered extensive erosion. Few fossils have so far been found in the lower portion of this series and only a few distinct gastropods in the upper portion. There are, therefore, differences of opinion regarding the geological age of this series but it should probably be regarded as a transition stage between the Cambrian and the Ordovician.

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[1] Paper read before Section C of the British Association for the Advancement of Science, Portsmouth meeting, 1911. The discussion showed that siliceous oölites are plentiful in England in rocks of similar physical character and geological age, but such satisfactory evidence of their origin by replacement of calcareous oölites had not been previously found.

Above this transition series, which is exposed only in the eroded crests of the anticlines, there are several thousands of feet of fossiliferous limestones which may be regarded as typically Ordovician and these are overlain by about five hundred feet of Utica shale of the Upper Ordovician. Following the shale are the Medina conglomerate and sandstone, which occupy the synclines of the original folds and cap the present mountains.

THE TRANSITION SERIES

The greatest interest in this area centers around the transition series. It shows very frequent alternations of dark, crystalline, magnesian limestone through oölitic limestone, arenaceous and very fine grained, white limestone to calcareous and also nearly pure white sandstone. With these strata occur numerous beds of chert and siliceous oölite, some iron ore and cherty sandstone, the latter due to secondary infiltration of silica and iron. Many of the limestone beds show numerous cavities which have been formed by solution and these are often partly filled with quartz or calcite, indicating extensive transportation of mineral matter.

The mixture of sand and limestone has produced conditions favorable for a great amount of water circulation and chemical activity and the ready disintegration of this series of rocks, with the result that vast quantities of loose sand, and fragments of chert and sandstone have been left on the surface, destroying the agricultural possibilities where the series is exposed and producing the area locally known as the "Barrens."

CONCRETIONARY STRUCTURES

There are a variety of concretions occurring in the region under discussion. In the Utica shale there are many limonite concretions consisting very largely of argillaceous material but often containing much lime. They are usually in the form of flattened ovals and have been developed since the formation of the shale.

Throughout the Ordovician limestone but especially in the lower and dolomitic beds of the system there are great numbers of chert and flint concretions. In some cases these bodies possess the forms of sponges, and although they have been so much altered that they cannot be definitely identified as sponges, they are believed to be remnants of these animals and it is believed that sponges originally supplied some of the chert around which most of these concretions were built up. Some of these bodies of chert possess a distinctly concentric arrangement, while others are very irregular and often very large. In a few cases these masses of quartz and chert are as much as three feet in diameter and appear to have been cavity fillings in the limestone. The silica varies in composition from flint and chert to rock crystal and in some cases gradations from chert to the phanerocrystalline variety in massive form may be observed in the same body.

Of considerable economic importance are the beds of limonite in the transition series. This mineral forms concretions in the decomposed limestone beds where the limestone has been replaced and fills cracks in a brecciated sandstone which is interbedded with the limestone. These concretions are sometimes a couple of feet in diameter, and are frequently hollow with the central cavity filled with water. When they are broken an explosive sound is produced, showing that they exist under a state of tensional stress. The formation of these bodies probably began by the deposition of iron oxide around the walls of a cavity filled with water and they grew by replacement of limestone.

The source of the iron is believed to be found in the pyrite in the shales and limestones of the Ordovician, in the red sandstones of the Silurian, and probably in the limonitic and sideritic shales and sandstones of the Carboniferous, which have been removed by erosion, leaving their iron contents to be carried downward by meteoric waters. The rapid solution of the interbanded calcareous sandstone and limestone strata permitted a slumping of the solid sandstone, thus producing an extensive sandstone breccia to be cemented with iron oxide.

The most interesting concretions in this area are, however, the calcareous and siliceous oölites.

CALCAREOUS AND SILICEOUS OÖLITES

Calcareous oölites are of such common occurrence that they require but a brief description here. Several beds of them occur in the transition series in the vicinity of State College and in limestone which has been largely recrystallized. They vary in size from 1.35 mm., the largest measured, to 0.22 mm. in diameter. They have not been seen in the very fine-grained limestone of the series. Their presence in thin sections is often indicated by a single outer circle but at other times the concretion consists of several concentric spheres. There is generally a nucleus of some sort in

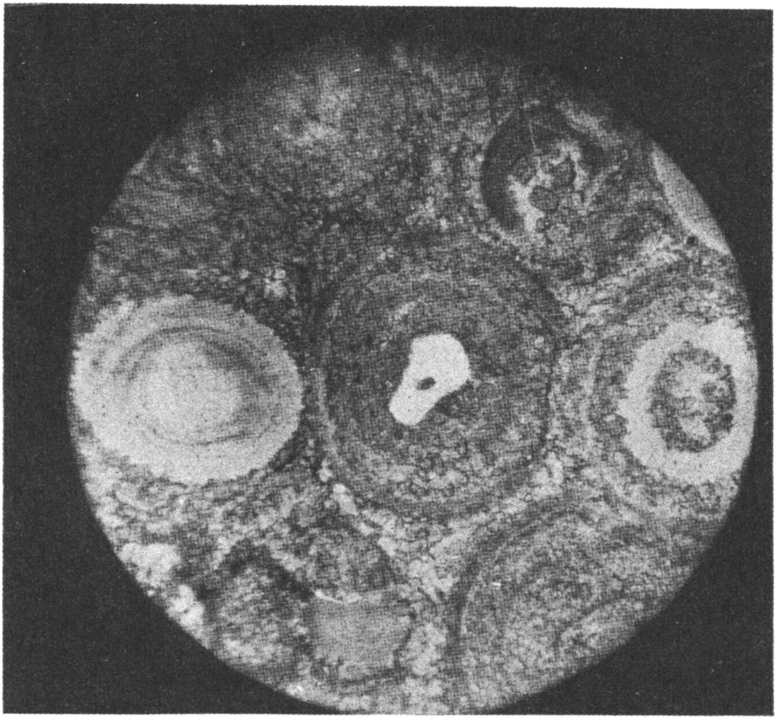

FIG. 2.—Photomicrograph of a calcareous oölite with sand grain as nucleus. ×45

the center of the concretion. This is frequently a sand grain and grains have been found varying from 0.6 mm. to 0.04 mm. in diameter and it is believed that some small body has in all cases served as a nucleus. In a few cases what appear to be recrystallized fragments of limestone serve as a central body.

The occurrence of these concretions is believed to be due to the intermixture of sand grains and calcium carbonate. The fact that limestone-conglomerate beds are associated with these rocks suggests that the sea was near the critical level in this area, and portions of limestone, probably not thoroughly consolidated, were from time to time exposed to erosion by fresh water or broken up by shore waves, resulting in the supersaturation of the sea water with calcium carbonate and the deposition of oölitic limstone near the shore. Beds of well-rounded sand grains underlying the oölite beds suggest further a sea advancing upon deposits of wind-blown sand mixed with a certain amount of limestone.

Although siliceous oölite has been reported as occurring in Missouri and Tennessee, it is not a common type of rock in this country. The area in Pennsylvania has therefore been a notable one, although never thoroughly described. Dr. G. R. Wieland wrote a brief description of the rock and as a result it has locally been known as Wielandite and sold by some mineral dealers under that name.[1]

The area in which it occurs in large quantity covers about forty square miles and it is scattered sparingly over a much larger area. It has been reported from the Chambersburg, Pa., area about seventy-five miles south of State College and in rocks of similar age and physical character.[2] The rock occurs in large quantities as broken fragments on the surface and in the form of larger concretionary masses of chert. There are as many as six beds of the rock lying one above the other in the limestone, from five to twenty feet apart. The beds are generally thin, varying from an inch to twenty inches in thickness, and often extremely irregular. The oölites are often nearly white in a dark matrix and almost black in a light-colored matrix. They consist of chert or flint and when

[1] *Am. Jour. Sci.*, 4th ser., IV (1897), 262.

[2] *U.S.G.S., Folio 170.*

polished some specimens make attractive ornaments. The solid oölite rock may grade over into chert with few oölites, and further, to solid chert. The oölites frequently occur in concretions of chert, thus showing a mass of small concretions forming a larger one.

A complete sand grain often forms the nucleus of these concretions but frequently the sand grain is partially or wholly granulated just as quartz grains are in highly metamorphosed rocks, and it is difficult to explain how these could be broken by compression without deforming the concretion, which often remains perfectly round, unless a recrystallization of the oölite as a whole has occurred. In the ability of concretions to reform and recrystallize under metamorphic conditions, as well as in the marked similarity which concretions of any mineral possess in widely separated regions they show a striking similarity to crystals. While so far as

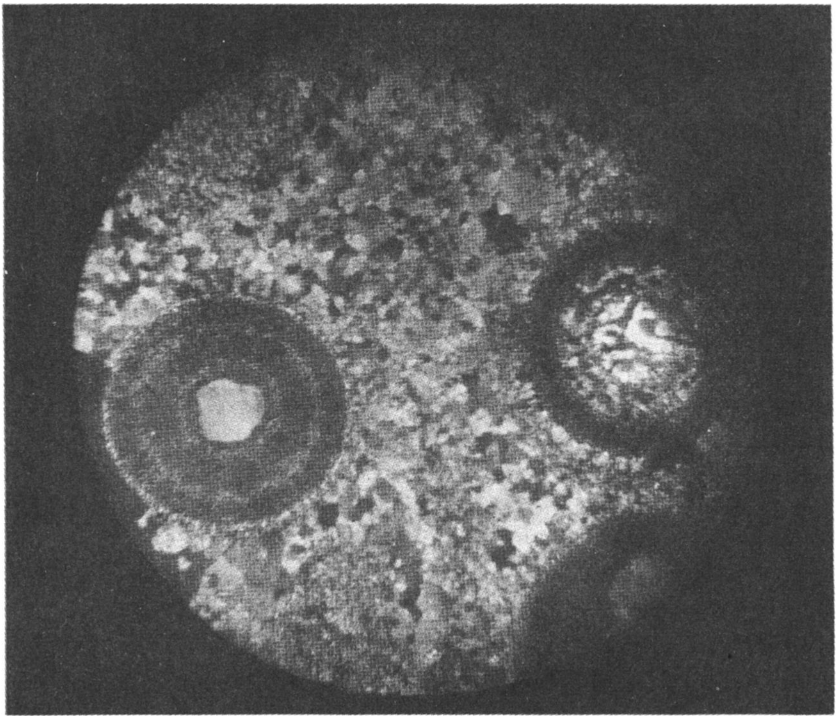

FIG. 3.—Photomicrograph of a siliceous oölite with a sand grain as nucleus. ×35

our knowledge of these bodies goes there is not so intimate a relation between the external form and the molecular structure as there is in crystals, there must be some relation on a larger scale, though less perfect, and it is probable that when concretions are more fully understood it will be found that their structures, like those of crystals, are all developed according to definite laws.

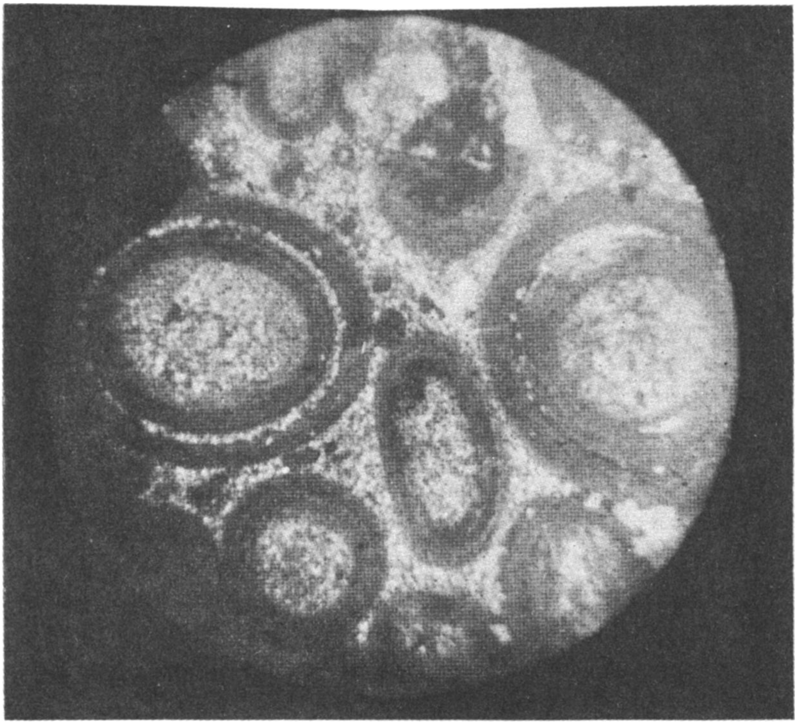

FIG. 4.—Photomicrograph of siliceous oölites imbedded in a chert ground mass. ×45

ORIGIN OF THE SILICEOUS OÖLITES

Two theories have been suggested for the origin of the siliceous oölites. In his article on "Eopaleozoic Hot Springs and the Origin of the Pennsylvania Siliceous Oölite,"[1] Dr. Wieland endeavors to show that they originated in the siliceous waters of hot springs. His statements, however, indicate a very limited knowledge of the rock, since he states that it occurs over an area of one square mile

[1] *Am. Jour. Sci.*, 4th ser., IV (1897), 262.

and has not been observed in place. I do not think there is much to justify his theory, as there is no evidence of igneous activity anywhere in the vicinity nor other geological features to suggest the presence of hot springs.

The other theory, and the only reasonable one to my mind, is that they originated by the replacement of limestone. This explanation was suggested by Barbour and Torrey who made some microscopical examinations and chemical analyses of these rocks without seeing them in the field.[1] The following analyses were made by these men and show a variation in composition from

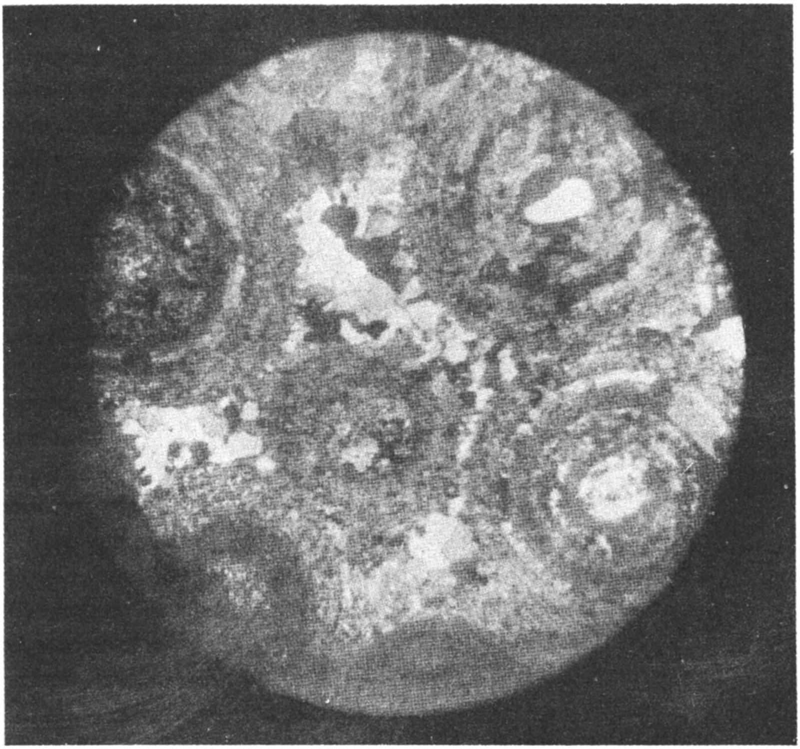

FIG. 5.—Photomicrograph of calcareous oölites in various stages of alteration to siliceous oölites. ×45.

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[1] "Notes on the Microscopical Structure of Oölites with Analyses," *Am. Jour. Sci.*, 3d ser., XL (1890), 246–49.

silica 3.70 to 95.83 per cent and calcium carbonate from 88.71 to 3.45 per cent—thus a gradation from calcareous to siliceous oölite.

	I	II	III	A Single Oölite
	Per cent	Per cent	Per cent	Per cent
SiO_2	3.70	56.50	95.83	SiO_2 99.99
$Fe_2O_3+Al_2O_3$	1.42	1.50	2.93	FeO 00.01
$CaCO_3$	88.71	16.84	CaO 1.93	
$MgCO_3$	8.09	2.60	MgO trace	
Water	.....	12.54	.....	

This alteration is well illustrated in Fig. 5 which shows various stages in the process of replacement. In most cases the replacement begins around the sand grain in the center, if one be present, due probably to the chemical influence of the silica already present in the oölite; but if there be no sand grain as a nucleus this process is more likely to begin in one of the outer rings of the concretion. A number of slides having been examined in conjunction with field observations, there remains no doubt that these siliceous oölites originated by replacement of the calcareous forms.

THE SOURCE OF THE SILICA

The source of the silica is to be found in the cherty remains of sponges and other animals and in the sandstones. According to Van Hise, the organic silica is more readily dissolved than the mineral silica and it is true that in this region the cryptocrystalline variety of the mineral has been much more largely transported than the phanerocrystalline. There are good examples of the solution of chert in a brecciated chert bed in which the fragments have been rounded off and silica deposited along the fractures as cement. In the sandstones there are numerous examples of the partial solution of sand grains and the movement of the silica along cracks in the rocks. This feature is well illustrated by Figs. 6 and 7, where sand grains may be seen which are partially dissolved and the material redeposited in a granular condition.

It is more difficult to account for the agent which dissolved the silica in this area. Hot water would be an active agent if present, and although the heat developed during the mountain-building period must have been considerable there are no metamorphic changes of sufficient importance to justify the conclusion that the heat became great enough to effect the solvent action of the meteoric water to any appreciable extent. The presence of carbonic acid doubtless played a part but the extent of this action is uncertain. Alkali waters may have produced important effects but we have no proof that they were present in large amounts and we must therefore turn to organic acids as a recognized agent of importance

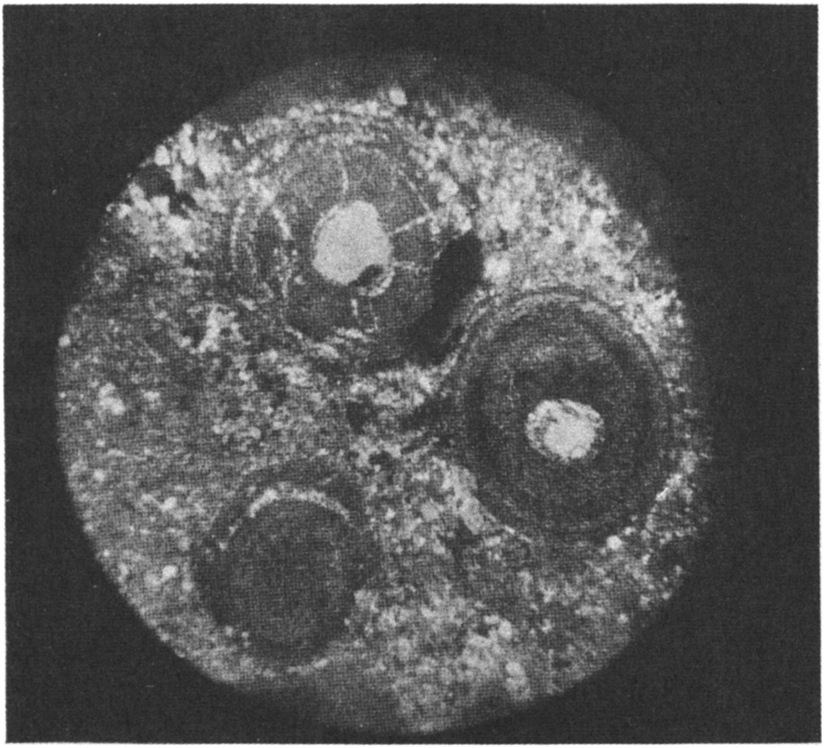

FIG. 6.—Photomicrograph illustrating solution and transfer of silica. ×45

and one which has doubtless been very active in this area since it emerged from the sea. In the bulletin, *The Data of Geochemistry*, F. W. Clarke has presented evidence of the great influence of organic acids in the solution of silica.[1] A. A. Julien, T. Sterry Hunt, and many others have made important observations and experiments on the solvent action of these acids, and since there is reason to believe that these agents have been at work for extended periods of time and the solution and transportation of iron and silica are known to be going on at the present time under their influence, it seems reasonable to conclude that organic acids may be regarded as the most important agent in the formation of these siliceous oölites.

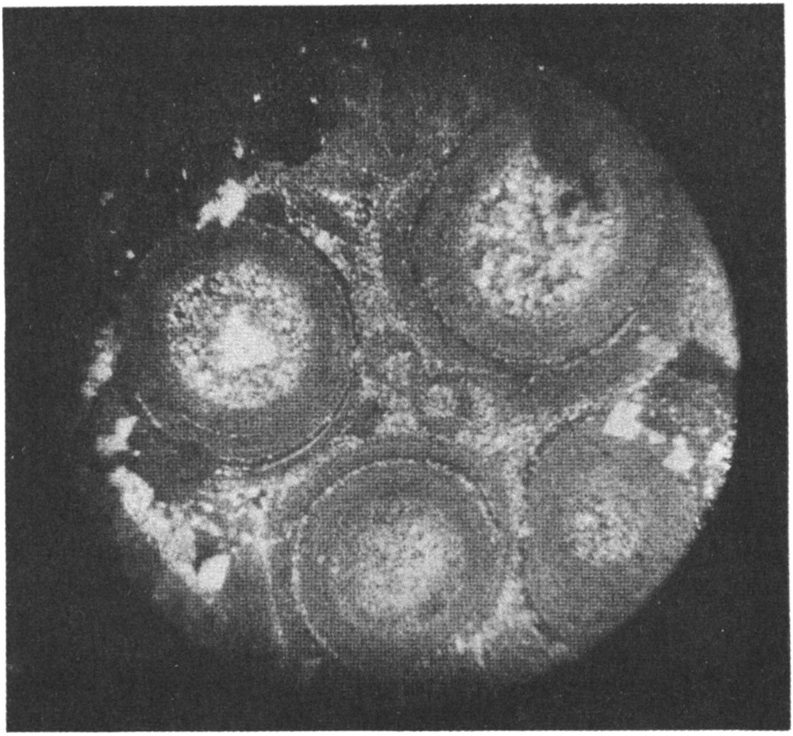

FIG. 7.—Photomicrograph of oölites, illustrating the solution and granulation of the sand grains forming the nucleus of the concretions. × 45.

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[1] *Data of Geochemistry, Bulletin 330, U.S.G.S.*, p. 84.